Toward the Use of Phase Change Materials (PCM) in Concrete Pavements: Evaluation of Thermal Properties of PCM

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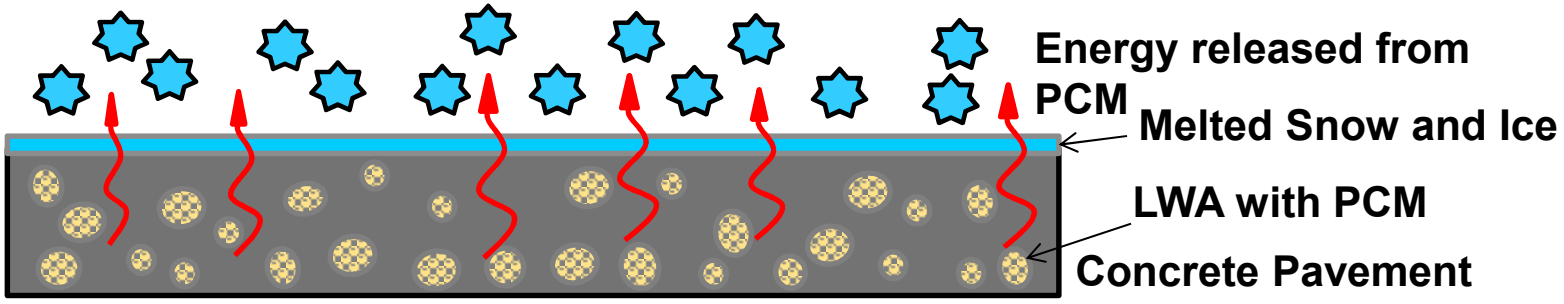
Introduction

- To increase the safety of airfield pavements, snow & ice should be removed during winter.
- Common practices include the use of snowplowing or the use of deicing chemicals.
- These methods are costly, have environmental impact, can damage the pavement, & can be labor intensive.

Is There Any Alternative to Remove Snow and Ice?

Main objective: To examine the role that PCM may have in storing heat in pavements to melt snow and ice at airports.

- PCMs can store thermal energy from the environment.
- Stored energy can be released and melt ice and snow.
- Improves anti-icing practices in airfield pavements.
- Increases the safety of airport pavement.



Potential PCMs for Airport Pavement Application

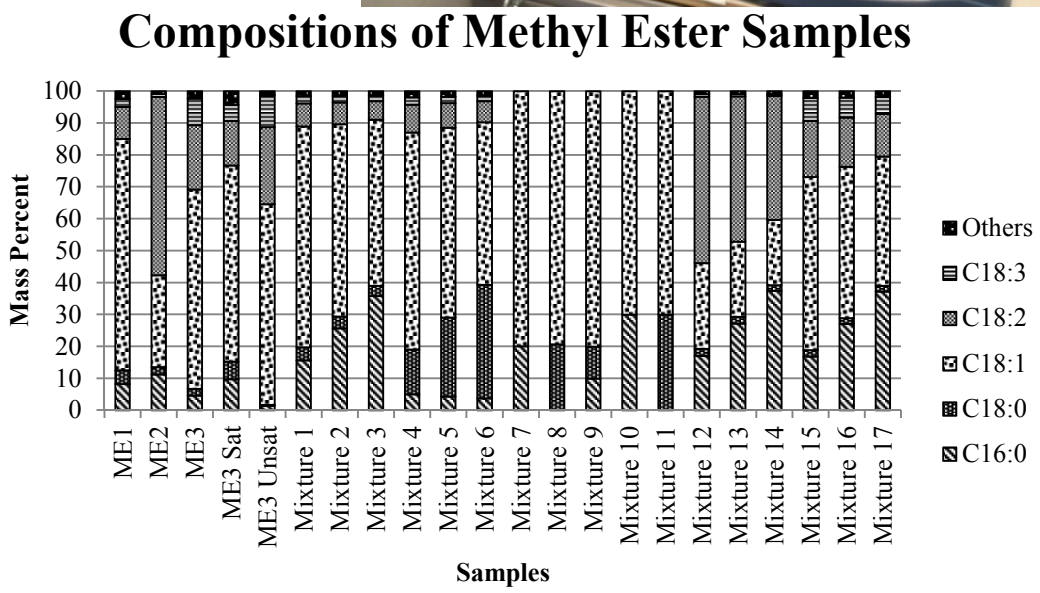
- Desired thermal properties:
  - ✓ Phase transition temperature near 3-6° C
  - ✓ High latent heat of fusion
  - ✓ High specific heat (heat capacity)
  - ✓ High thermal conductivity
- Desired physical properties:
  - ✓ High density
  - ✓ Small volume change between phases
  - ✓ Low vapor pressure
- Desired chemical properties are stability, compatibility with concrete, non-toxic, and non-flammable.
- It is economic/commercially viable

Experimental Program

1. First, PCM thermal behavior was determined using low temperature differential scanning calorimetry (LT-DSC).
2. Second, ways that PCM can be incorporated in airport pavement were evaluated.
3. Potential PCMs that can be used in airport pavement were chosen.
4. Finally, concrete samples were prepared using those PCMs and tested in longitudinal guarded calorimeter (LGCC) to determine the concrete thermal behavior.

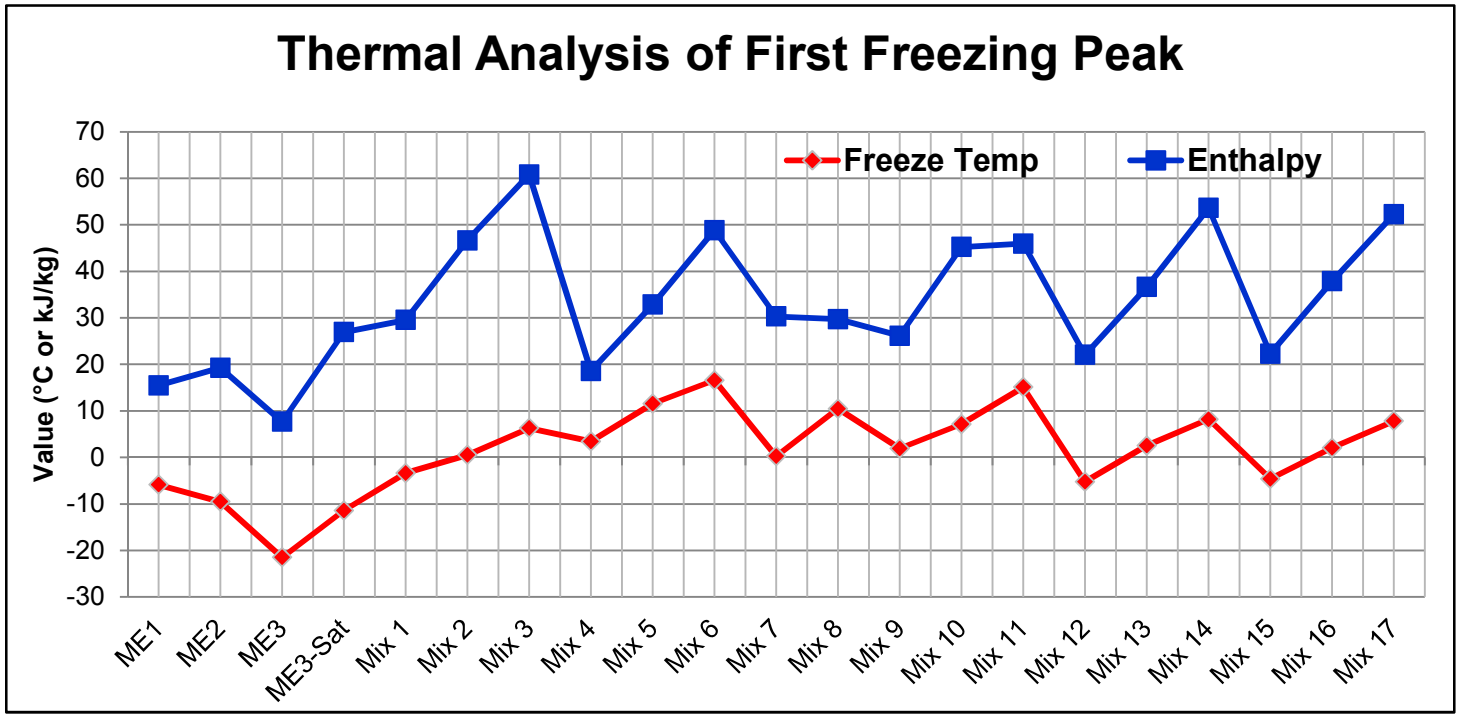
Part I: Low-Temperature Differential Scanning Calorimeter (LT-DSC)

- This is a quick test to assess optimal PCMs and to evaluate the thermal properties of PCMs.
- Many PCMs were tested:
  - Soybean oil
  - Canola oil
  - Corn oil
  - Coconut oil
  - Paraffin oil
  - Fatty acids methyl ester



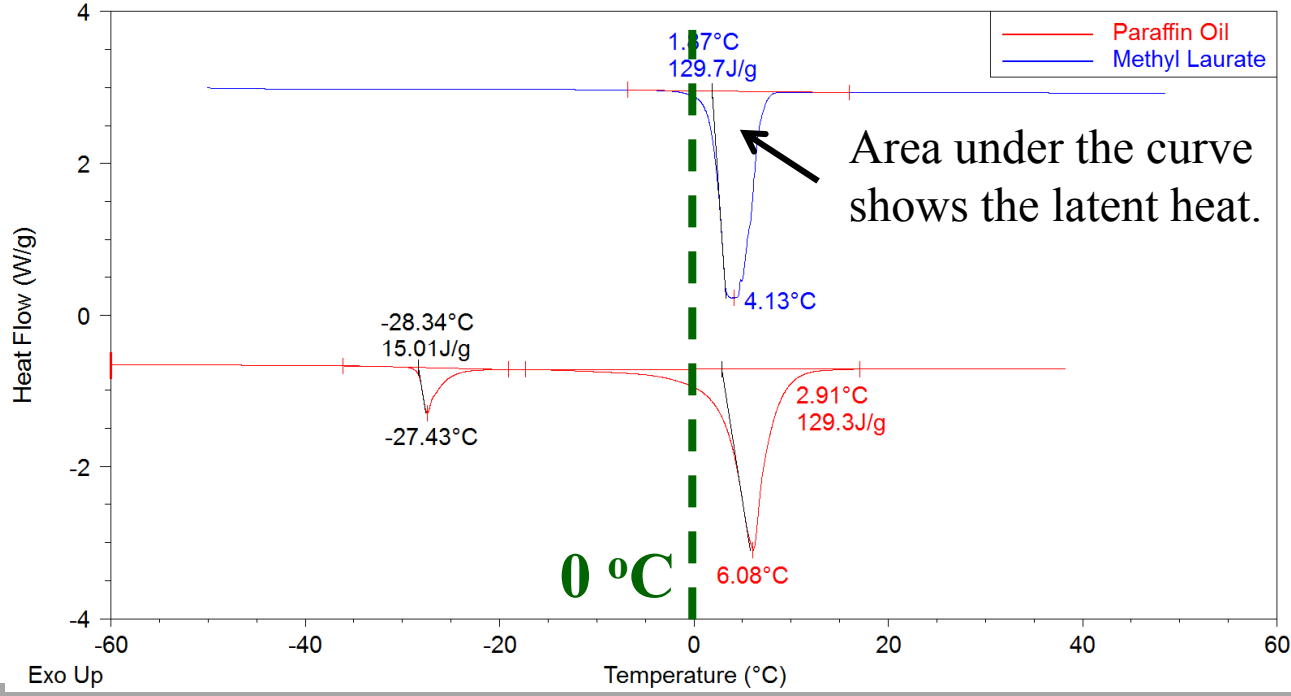
LT-DSC - Results

- By changing the composition of PCMs, their freezing temperature and enthalpy of fusion changes.
- We are able to change PCM freezing temperature for different climate conditions.



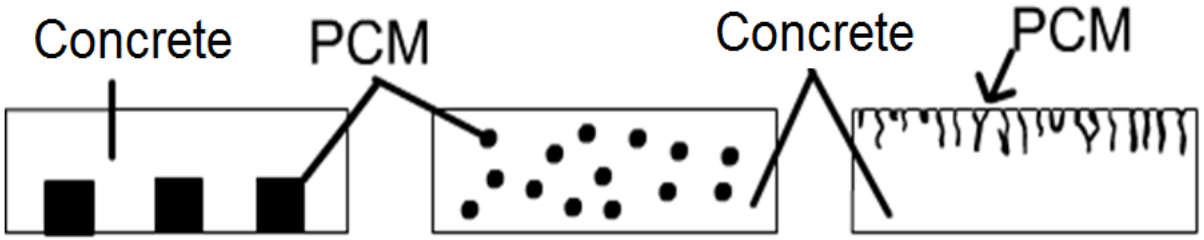
Candidate PCMs

- Among PCMs tested in this study, paraffin oil and methyl laurate have a desired thermal behavior for concrete pavement application.
- They have a freezing temperature near 3-6 ^{o}C and high latent heat of fusion



Part II: Ways to Incorporate PCM into Concrete Pavements (Use of LWA)

- Lightweight aggregate (LWA) can be used to incorporate PCM in concrete pavement.
- More PCM penetrates in LWA, more heat can be produced.
- LWA sorted by sieving and PCM absorption was tested.
- Two common types of LWAs were used:
  - Buildex and Haydite



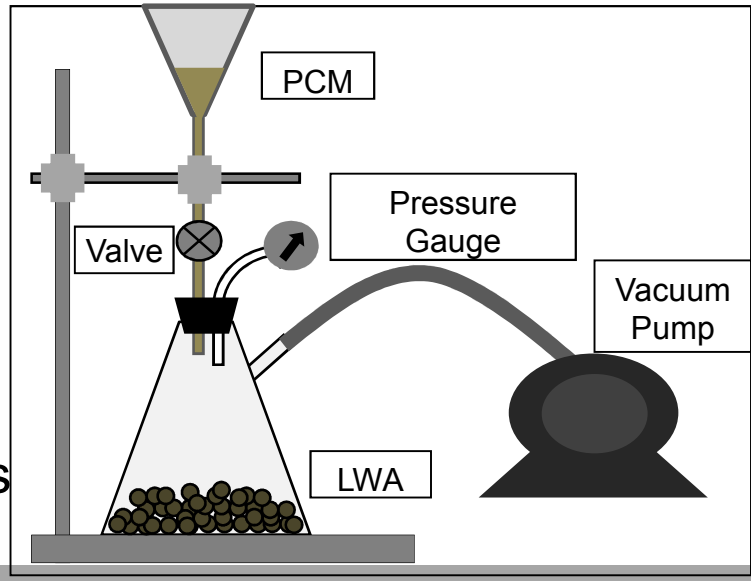
Part II: Absorption of PCM into LWA

- PCM absorption into LWA was evaluated in two conditions:

✓ Ambient Conditions
- 24 hours soak
- LWA towel dried for saturated surface dried conditions

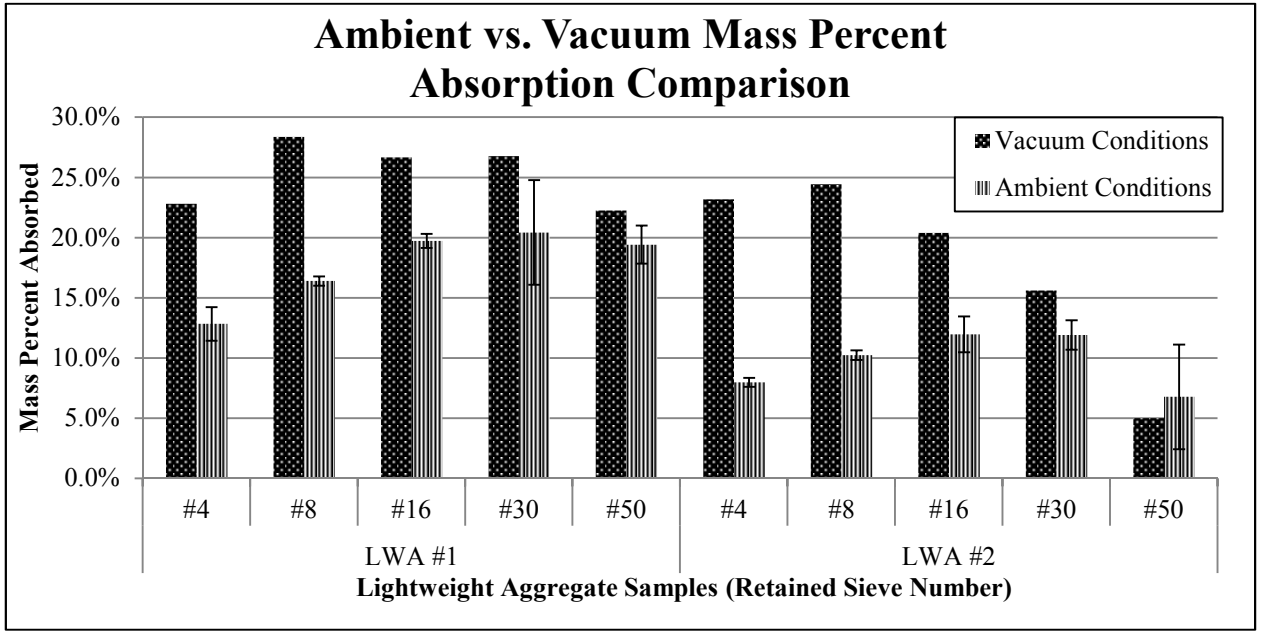
✓ Vacuum Conditions
- Evacuated air for 45 minutes
- Cover LWA with methyl ester sample
- Stop vacuum
- Methyl esters penetrate pores for 30 min

Sample	Retained Sieve #	Vacuum Water Absorption
Buildex	-	32%
Graded Buildex	8	35%
	16	33%
	30	31%
	50	29%
	Pan	26%
Haydite	-	23%
Graded Haydite	8	29%
	16	26%
	30	19%
	50	17%
	Pan	13%



Part II: Results / Important Findings

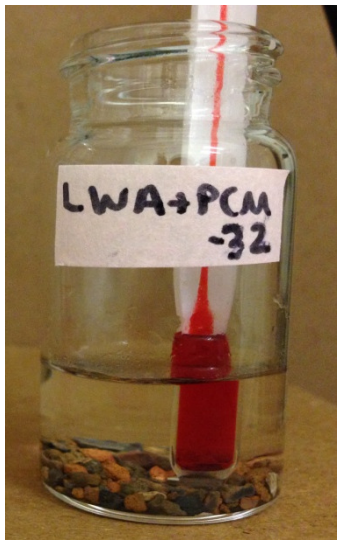
- As expected, vacuum absorption is higher.
- LWA#1 (Buildex) showed a better PCM absorption.

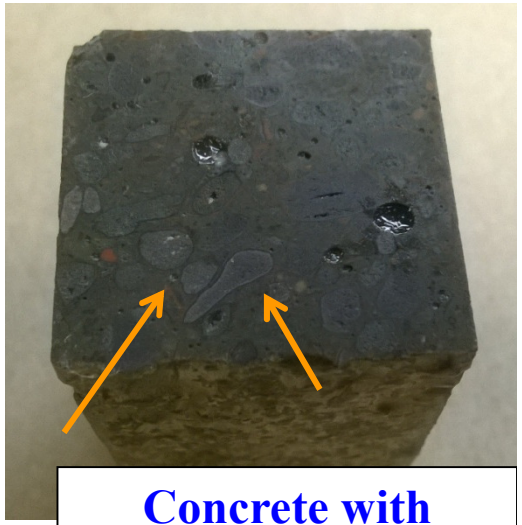


Part III: Make a Concrete with PCM

- Lightweight aggregates (LWA) were soaked in PCM and then were used to make concrete.
- The same procedure can be used in the field to make concrete pavement using conventional paving operations.

LWA





Concrete with LWA + Paraffin Oil

Next step: Longitudinal Guarded Comparative Calorimeter (LGCC)

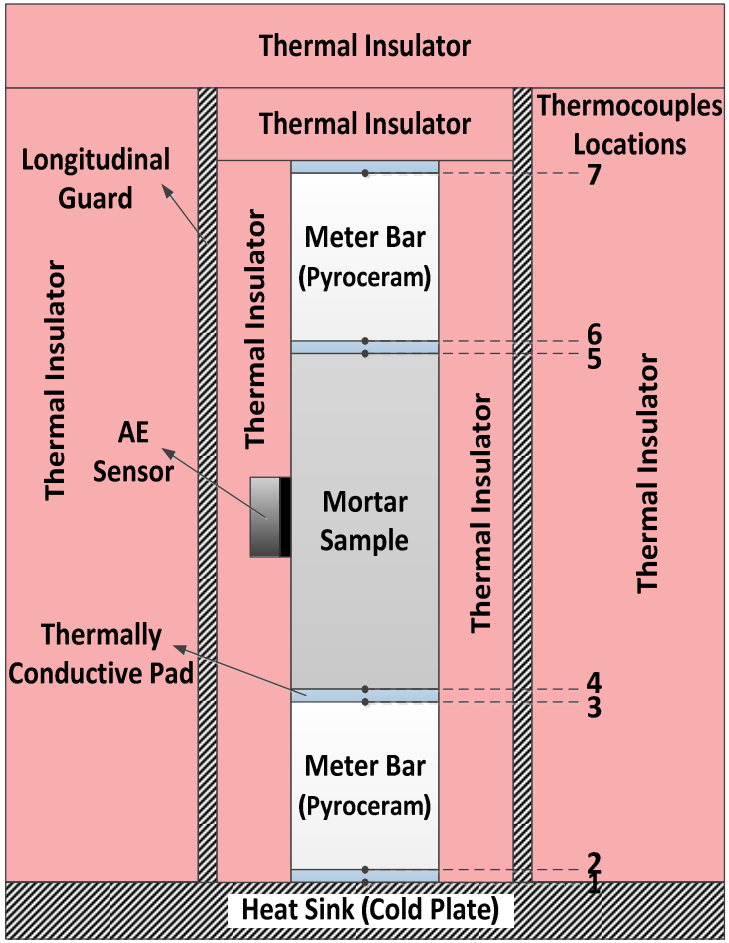
- Acoustic Emission Longitudinal Guarded Comparative Calorimeter (AE-LGCC).
- LGCC monitors heat flow and detects phase changes.
- AE can monitor damage and cracking in samples due to FT.
- Calculation of heat transfer based on meter bar:

$$\lambda_{PC} = -0.0061(T) + 4.2013 \qquad -50\ ^{\circ}C < T < 30\ ^{\circ}C$$

$$q_T = \lambda_{PC}.\frac{T_6 - T_7}{d_{PC}}$$

$$q_B = \lambda_{PC}.\frac{T_2 - T_3}{d_{PC}}$$

$$\Delta Q_{Sample} = (q_B - q_T).A$$



AE-LGCC with an operating range of -40 °C to +60 °C

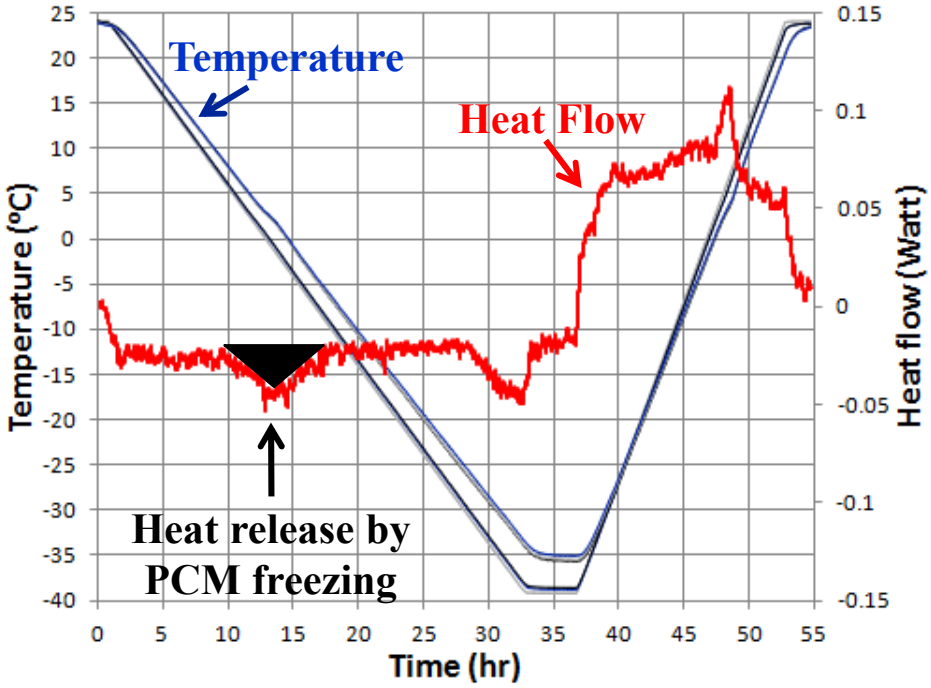
LGCC – Preliminary Results (Paraffin Oil)

- Concrete made by LWA and PCM showed heat releasing during PCM freezing.
- This can be used to melt ice and snow.
- Maximum amount of PCM used to make concrete.

✓ Released energy:
~ 130 kJ/kg

✓ Heat release time:
~ 5hr

✓ Freezing Temperature:
~ +4 °C to -3 °C



Summary

- This work discussed the feasibility of using PCM in concrete pavement and its capability to melt ice and snow.
- Thermal behavior of PCMs were monitored and candidate PCMs were chosen.
- Through using LWA, PCMs were incorporated in concrete.
- PCM concrete showed promising behavior in releasing heat under thermal cycling.
- This heat release can be used to melt ice and snow in the aviation infrastructure.

Next Steps in our Project

- More samples will be tested in LGCC.
- Full scale PCM concrete slabs will be prepared and will be tested in our environmental chamber at Purdue University.
- A finite difference model (FDM) is being developed to simulate PCM action in concrete pavement.
- Using FDM and historical climatic data a proper PCM can be selected for a specific region.
- Evaluate the mechanical behavior.